

β^* limitations

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Evolution of β^* in polarized proton runs

100 GeV:

RHIC pp Run	$\beta^* [m]$
Run-2	3.0
Run-3 – Run-8	0.9
Run-9	0.7

250 GeV:

RHIC pp Run	$\beta^* [m]$
Run-9	0.7

Only one 250 GeV run so far
Need to extrapolate β^* limitations from 100 GeV experience

Luminosity lifetime evaluation

Double-exponential fit:

$$L(t) = L_{\text{long}} \exp\left(-\frac{t}{\tau_{\text{long}}}\right) + L_{\text{short}} \exp\left(-\frac{t}{\tau_{\text{short}}}\right)$$

Using PHENIX luminosity during first 6 hours at store

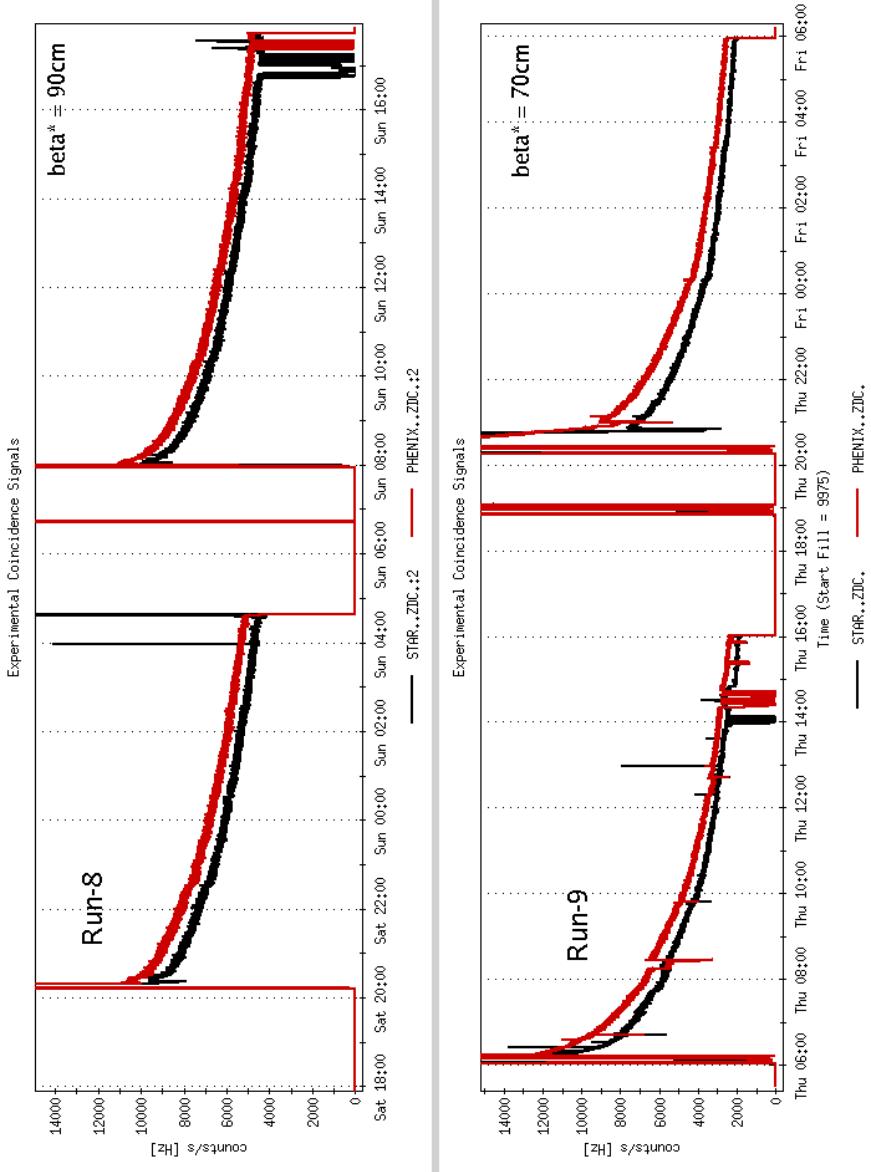
For typical 100 GeV proton stores in RHIC Run-2 to Run-8,

$$\begin{aligned} \tau_{\text{long}} &\approx 10 \text{ hours} \\ L_{\text{long}} &\approx 0.9 \cdot L(0) \end{aligned}$$

and

$$\begin{aligned} \tau_{\text{short}} &\approx 1 \text{ hour} \\ L_{\text{short}} &\approx 0.1 \cdot L(0) \end{aligned}$$

Typical 100 GeV proton stores in Run-8 and Run-9



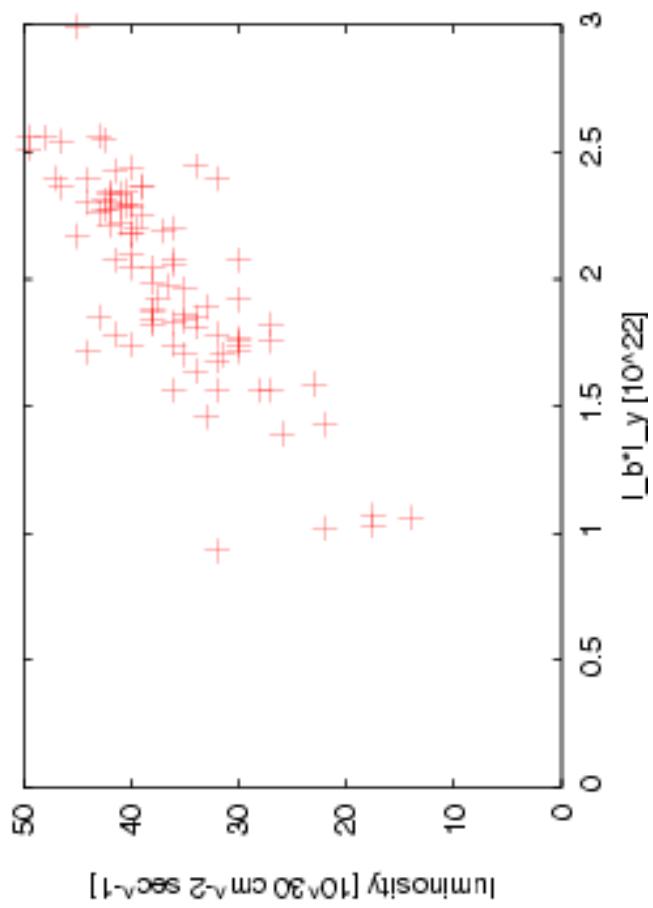
Luminosity lifetime τ_{l} in Run-9 was only 6 h, vs. 10 h in Run-8

Machine configuration for 100 GeV protons

- $10^9 \times 10^9$ bunches, $\approx 1.5 \cdot 10^{11}$ protons/bunch in Run-8, $1.35 \cdot 10^{11}$ in Run-9
- 2 collision points
- 75 kV/cavity RF voltage during the ramp, then fast ramp-up to 150 kV (2 cavities per ring)
- Local low- β triplet multipole correction for sextupoles, skew sextupoles, and octupoles. Scanned 10- and 12-poles in Run-9.
- $\epsilon = 20 - 25 \mu\text{m}$ in Run-8, $\epsilon = 15 - 20 \mu\text{m}$ in Run-9
- $\beta^* = 90 \text{ cm}$ in Run-8, $\beta^* = 70 \text{ cm}$ in Run-9
- $\xi = 0.011$ in Run-8, $\xi = 0.013$ in Run-9

Luminosity vs. bunch intensity product in Run-9

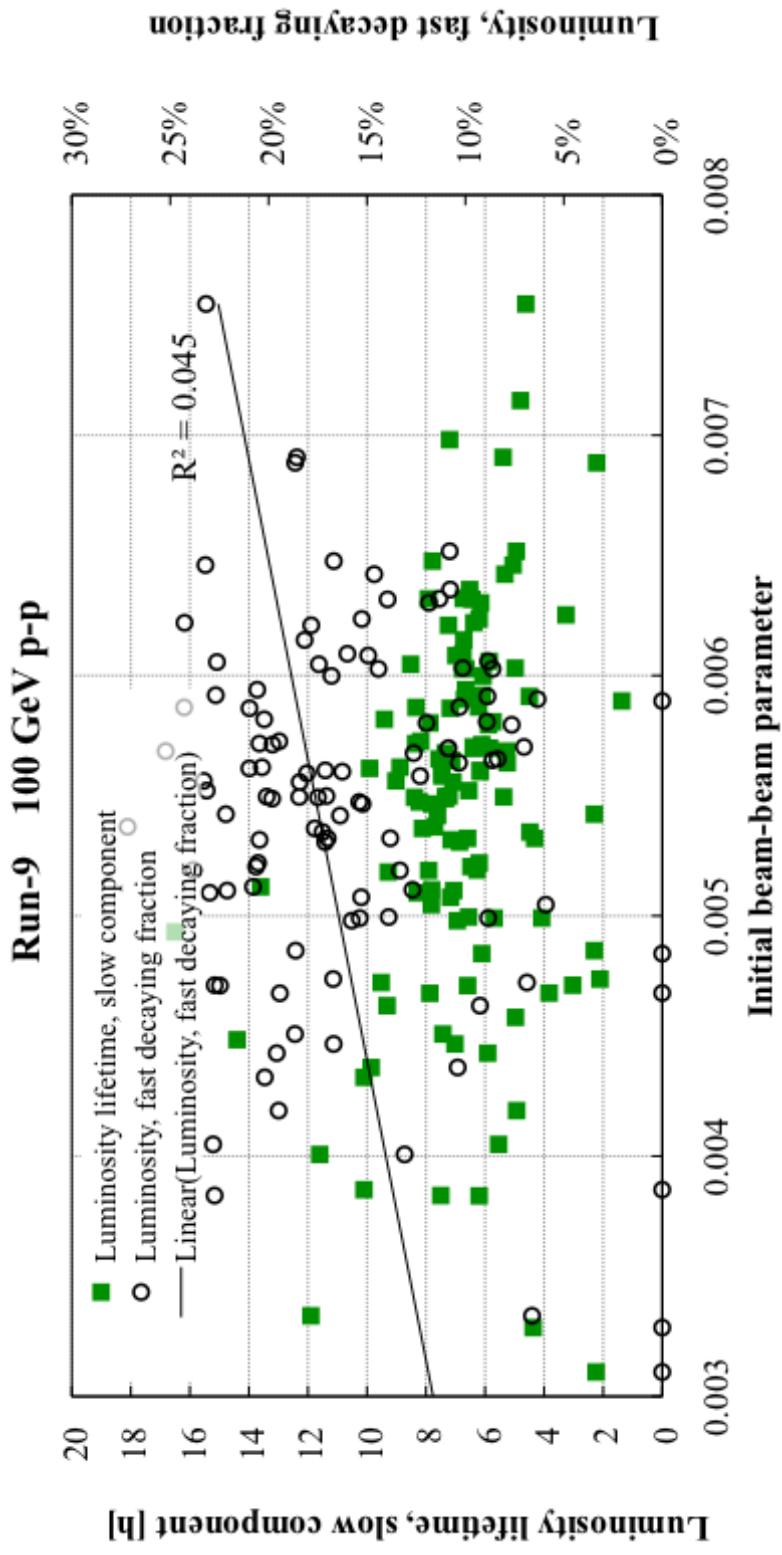
Peak luminosity after collimation and collision tuning



Linear increase indicates no beam-beam limit

Smaller emittance/larger beam-beam parameter does not seem to be a problem

Luminosity lifetime vs. beam-beam parameter



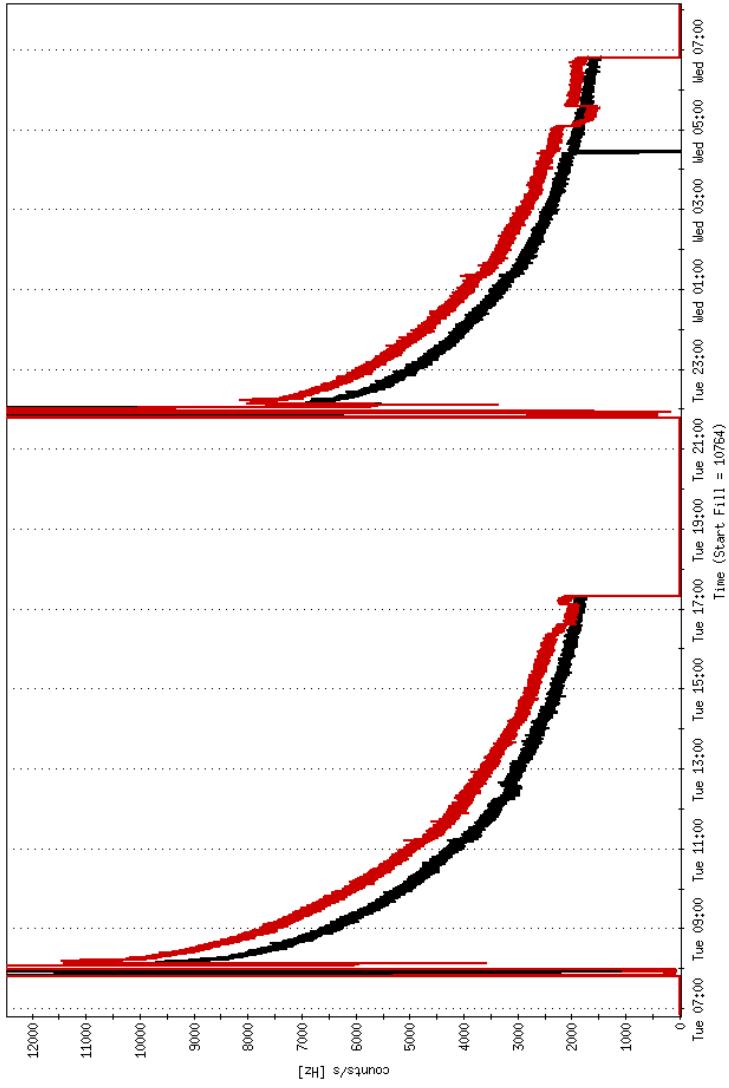
Little or no dependence of luminosity lifetime on beam-beam parameter

Larger beam-beam parameter is not the culprit

Configuration changes to investigate cause of poor lifetime

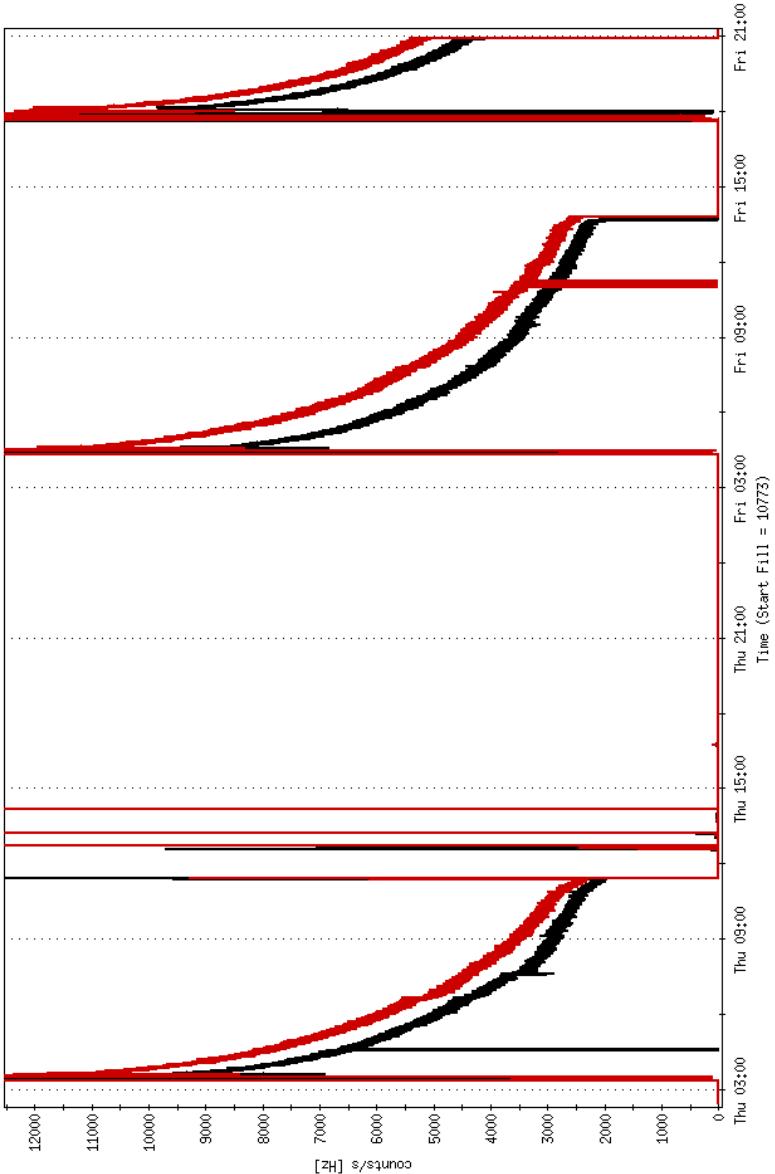
- Fewer bunches (electron cloud?)
- No RF voltage increase at store (momentum aperture?)
- Lower bunch intensity (beam-beam?), RF voltage increase over 3 hours
- RF voltage increase to 200 kV/cavity, over 9 h
- RF voltage increase to 150 kV/cavity, over 9 h
- $\beta^* = 80$ cm, by un-squeezing
- Re-load $\beta^* = 90$ cm from Run-8 (lattice issue or unknown noise source?)

Fewer bunches (84x84): 10764/10765



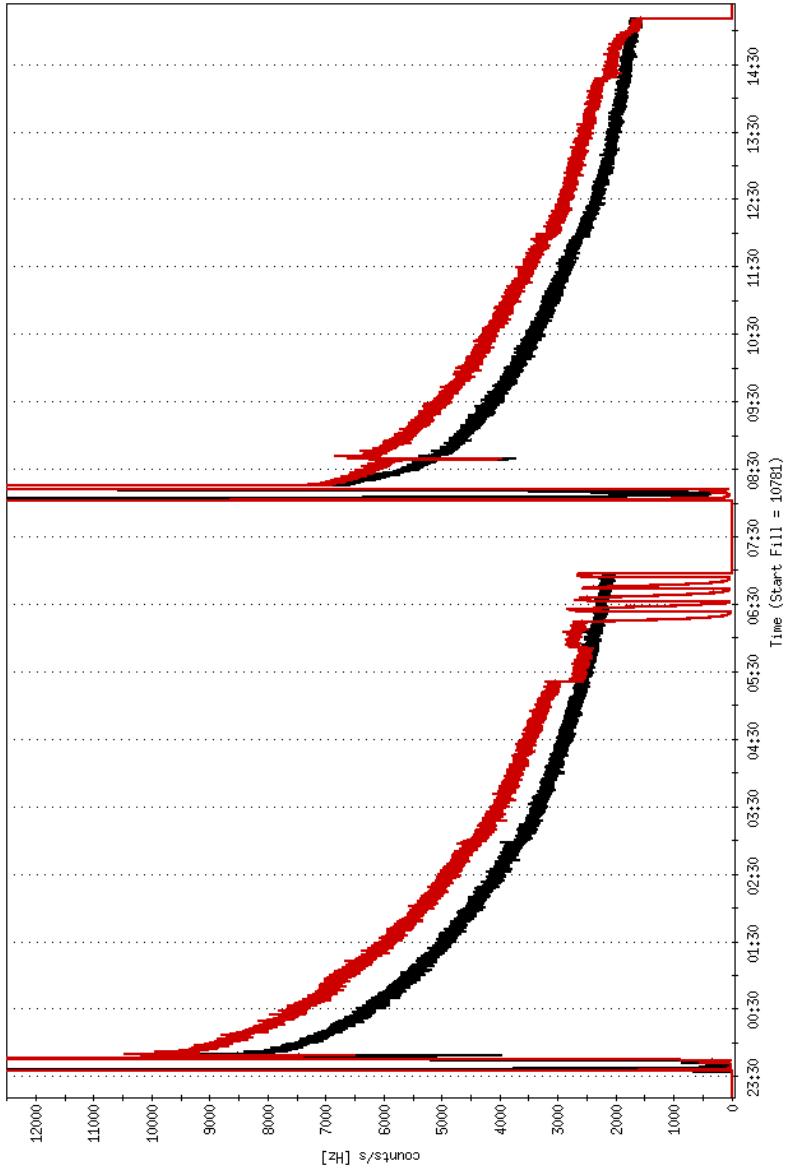
Luminosity lifetime: 6.8 h, for 80 percent of the total luminosity
Performance far below Run-8 (10 h for 90 percent of the total luminosity)

No RF voltage ramp at store: 10773 – 10778



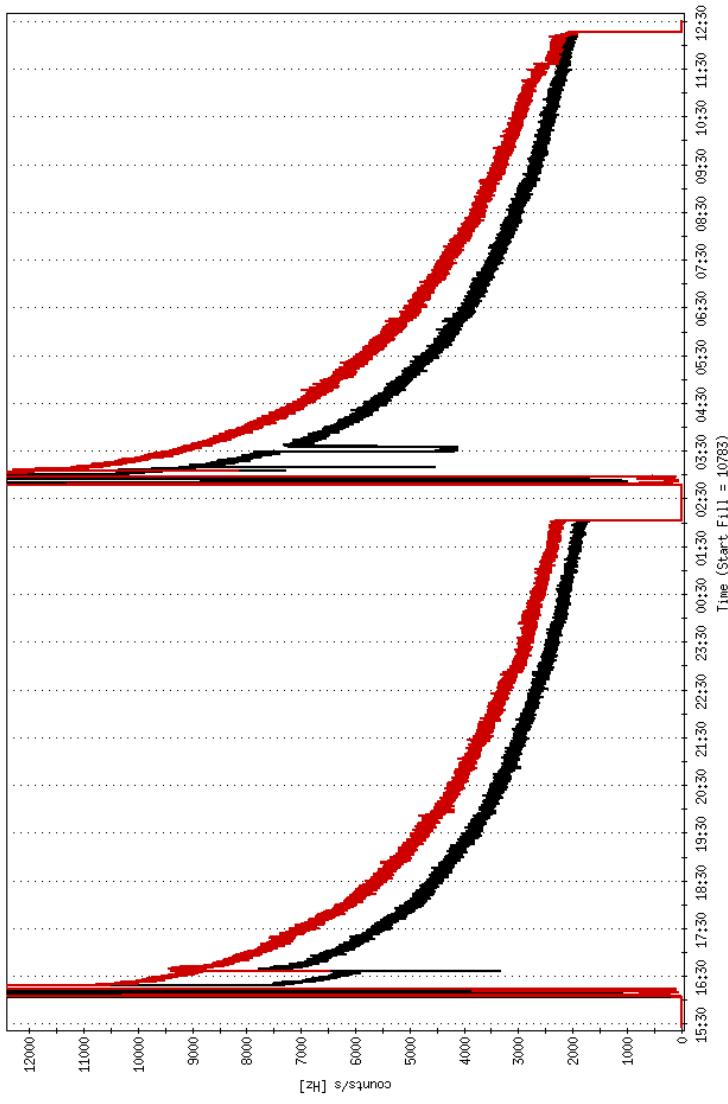
Luminosity lifetime: 6 – 8 h, for 75 – 80 percent
Performance far below Run-8 (10 h for 90 percent of the
total luminosity)

Low intensity stores (1e11), 3h RF ramp: 10781/10782



Luminosity lifetime: 6 – 6.5 h, for 90 percent
Performance far below Run-8 (10 h for 90 percent of the
total luminosity)

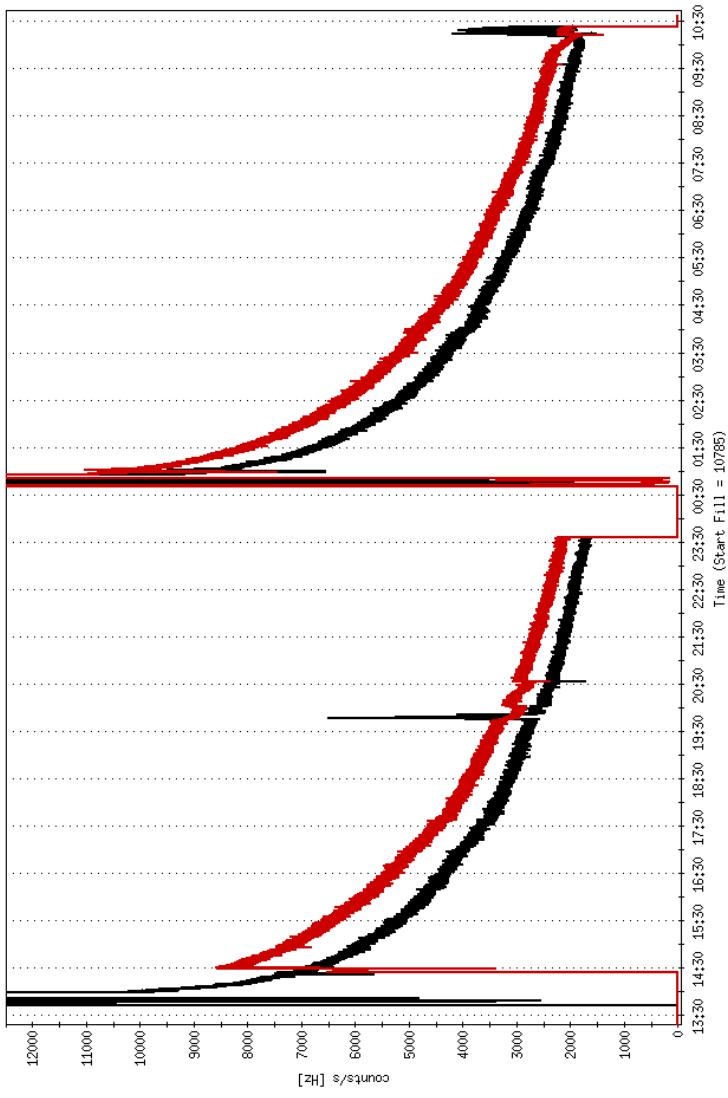
9h RF ramp to 200kV/cavity: 10783/10784



Luminosity lifetime: 8.9 h, for 80 percent of the total luminosity

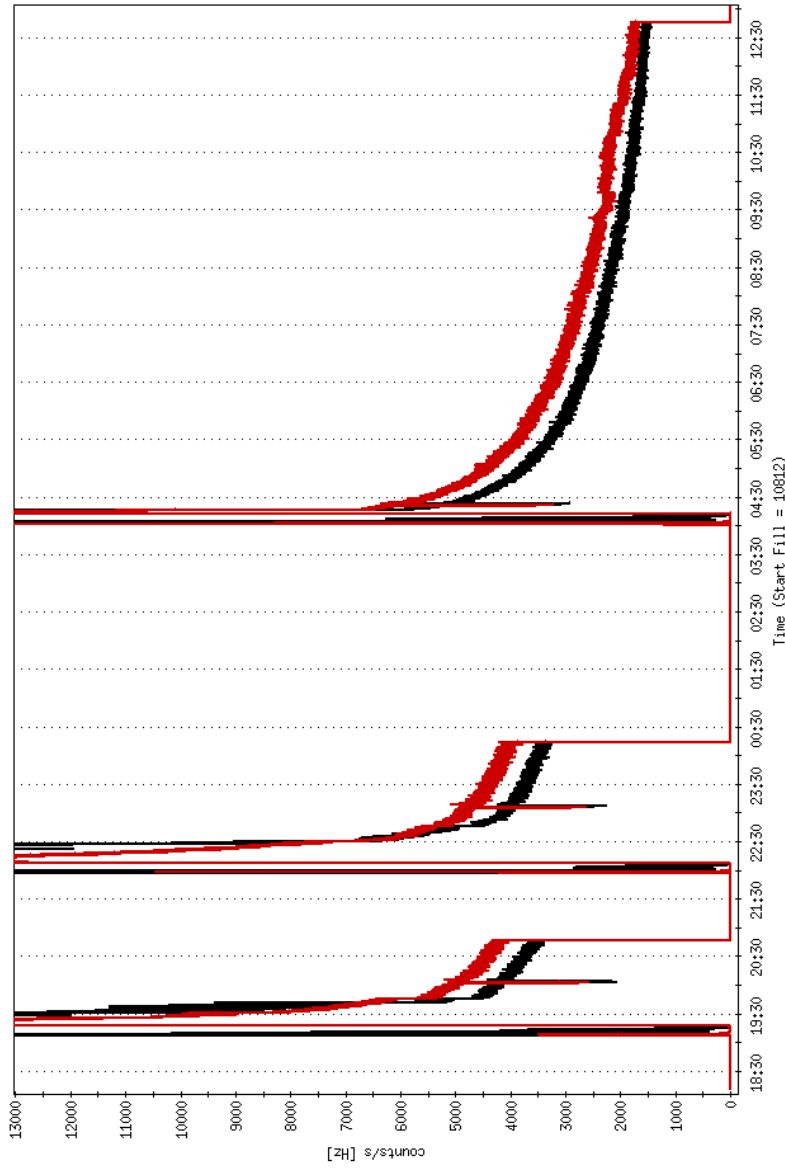
Performance far below Run-8 (10 h for 90 percent of the total luminosity)

9h RF ramp to 150kV/cavity: 10785/10786



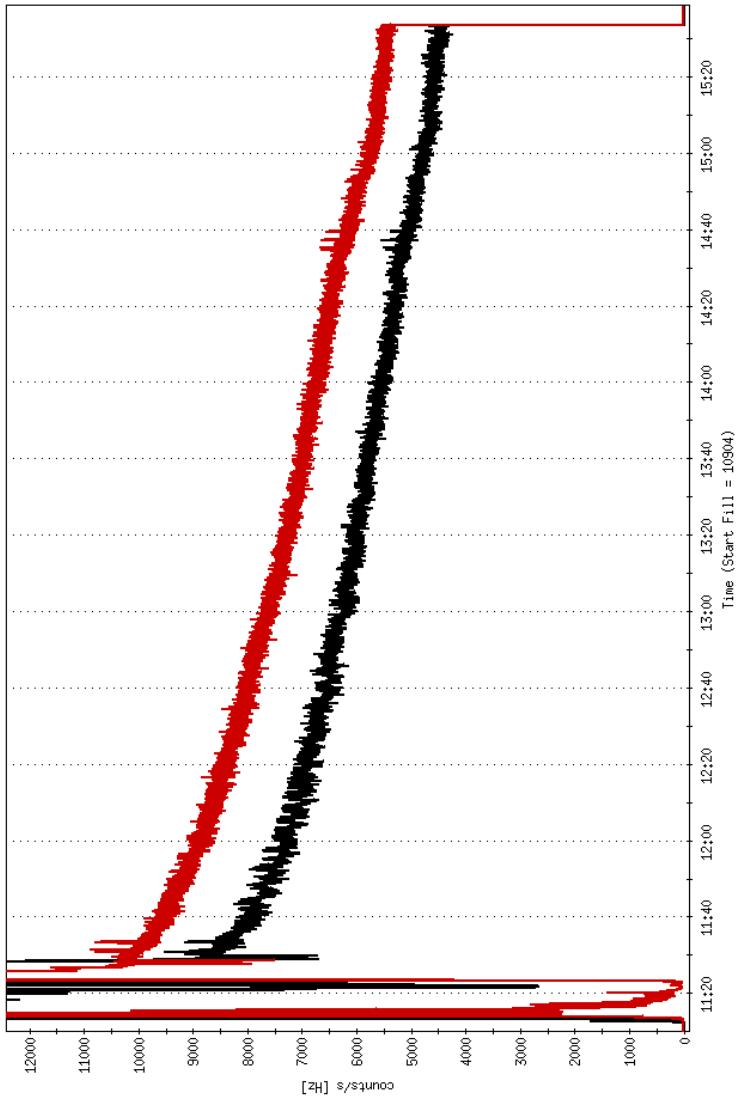
Luminosity lifetime: 7 – 8 h, for 75 – 90 percent
Performance far below Run-8 (10 h for 90 percent of the
total luminosity)

Unsqueezed to 80cm: 10812/10814



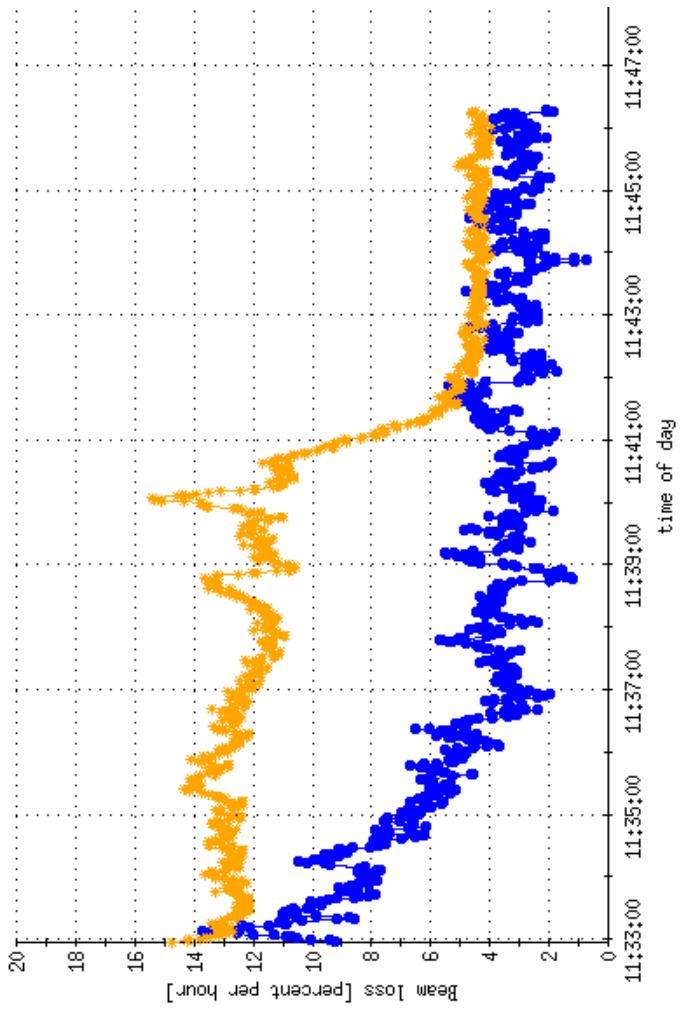
Luminosity lifetime: 11 h, but only for 60 percent
Performance far below Run-8 (10 h for 90 percent of the
total luminosity)

Increased transverse emittance by AtR flags: 10904



Luminosity lifetime: 8.3 h for 95 percent, during first 4 h
at store
Performance still below Run-8 (10 h for 90 percent of the
total luminosity)

Re-loaded $\beta^* = 90$ cm ramp from Run-8



4 percent beam decay at beginning of store, with 1.8e11 injected – similar to Run-8

70 cm stores started around 10 percent/hour

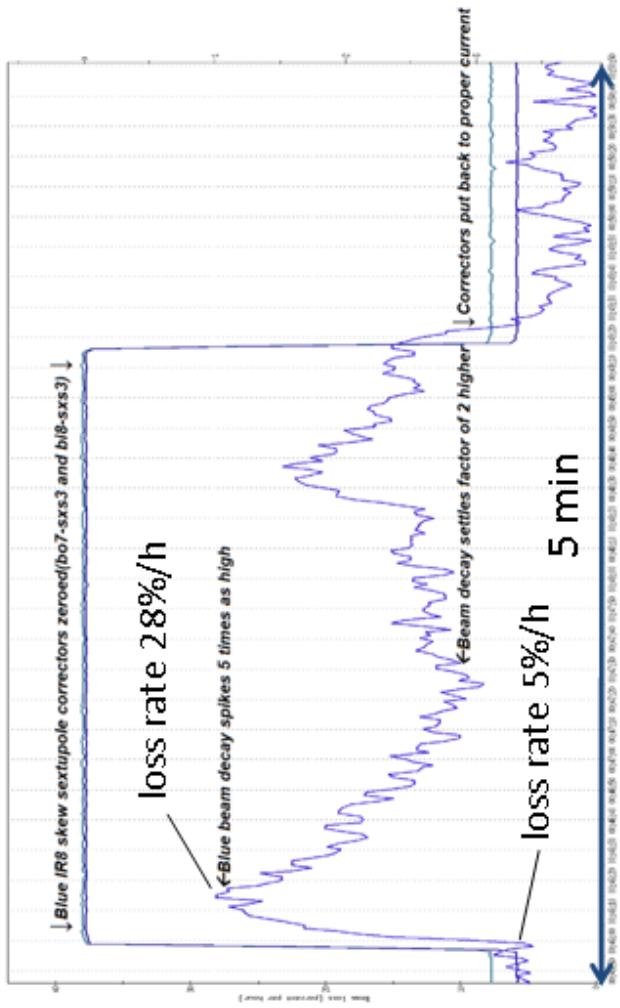
Did not spend enough time at store to assess luminosity lifetime

Nonlinear chromaticity correction

- Observed insufficient momentum aperture for rebucketing of 100 GeV/n gold beams with $\beta^* = 60$ cm in Run-10
- Beam-based measurement and correction of nonlinear chromaticity failed due to insufficient momentum aperture
- Model predictions not accurate enough for efficient correction
- Had to back off to $\beta^* = 70$ cm

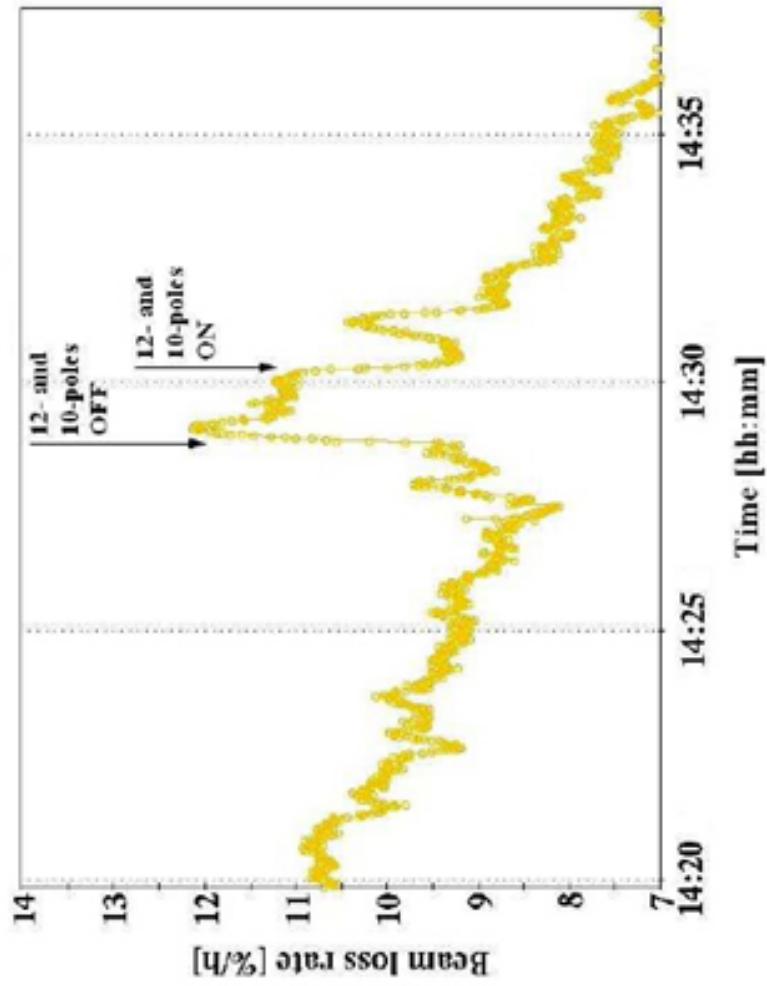
IR multipole correction

Effect of sextupole, skew sextupole, and octupole correction in IRs 6 and 8:



Settings based on measured tune shifts from orbit bumps in IR triplets

Effect of 10- and 12-pole correction in IRS 6 and 8:



Settings found iteratively based on observed beam loss rate

Expectations for 250 GeV protons

- Little experience; only one run so far, at $\beta^* = 70$ cm
- Power supplies and leads allow for minimum $\beta^* = 50$ cm
at 250 GeV
- Smaller emittance beam samples smaller triplet multipoles; $\beta^* = 90$ cm at 100 GeV equivalent to $\beta^* = 36$ cm
at 250 GeV
- Dynamic aperture simulations indicate similar DA for $\beta^* = 50$ cm at 250 GeV and $\beta^* = 90$ cm at 100 GeV if nonlinear chromaticity is corrected

Conclusions

- For 100 GeV protons, the dynamic aperture at $\beta^* = 70\text{ cm}$ is too small – consistent with DA studies
- At $\beta^* = 90\text{ cm}$, RHIC performed as in Run-8 – no new, unknown noise source
- Dynamic aperture simulations for 250 GeV indicate no problem at $\beta^* = 50\text{ cm}$ so far
- Nonlinear chromaticity correction is a must; has to be implemented at the lattice design stage
- β^* limit depends on IR multipoles; correction method well established at RHIC